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Warpage of Studs from Young Growth Ponderosa Pine from Northern New Mexico

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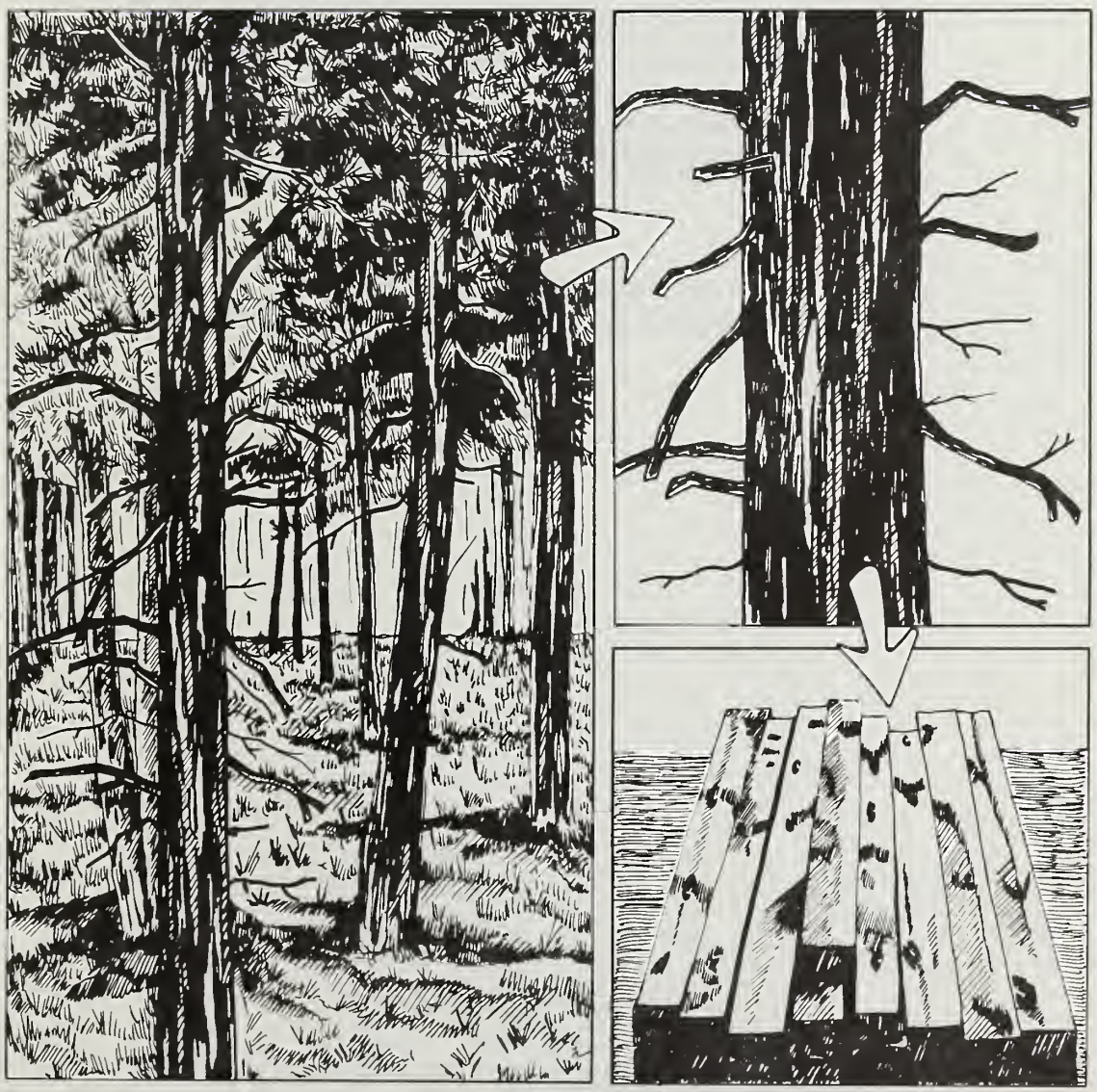

Abstract

Lumber grade recovery and warp of studs from young ponderosa pine trees are affected by tree diameter, but not by a difference in site index from 55 to 100 or log position in the tree. Trees 9 inches d.b.h. yielded lower grade studs with more warp than 10- through 14-inch d.b.h. trees. Logs 5-7 inches d.i.b. yielded lower grade lumber with more warp than 8-12-inch logs after drying to 6% moisture content. Subsequent drying simulating on-site storage indicated that kiln drying to 15% moisture content instead of 19% would not lessen warpage problems. Logs smaller than 8 inches d.i.b. from trees ranging from 9 to 14 inches d.b.h. produced lumber of similar grade and warpage.

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Contents

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Management Implications

Much of the dimension lumber from ponderosa pine (*Pinus ponderosa*) in the Rocky Mountains is dried to the industry standard of 19% moisture content, but then is marketed in dry areas where the equilibrium moisture content may be 5% or lower during much of the year. Further drying under these circumstances would increase any tendency for the lumber to warp.

A total of 865 studs were sawn from 82 trees sampled from 9- through 14-inch d.b.h. trees from Northern New Mexico. Analysis of the grade and warpage of the study indicated that:

1. Growing site index did not affect either the grade or the amount of warp.
2. Smaller trees and logs had lower grade recovery and more warp than larger trees and logs.
3. Log position in tree had little effect on grade recovery and warp when log diameter was accounted for.
4. Logs 8 inches or less in diameter, regardless of location in tree, had similar grade and warpage, and were affected only by moisture content.

These research results should help the buyers and sellers to determine the stumpage value of timber.

Introduction

The relationship between drying degrade in lumber from young growth ponderosa pine and size and other characteristics of this class of trees is not well understood. It has been reasoned, with some supporting evidence, that an unusually high incidence of degrade in such timber is caused by juvenile wood and/or compression wood. Both of these characteristics may be more prevalent in young growth ponderosa pine than in mature trees.

Loss of lumber grade from excessive warp usually results from abnormal shrinkage when lumber dries. Longitudinal shrinkage typically ranges from 0.1% to 0.3% when wood is dried from green to ovendry conditions. This shrinkage would be about one-half as much when lumber is dried to 12% moisture content. Longitudinal shrinkage greater than 0.3% from green to ovendry moisture conditions for straight grain material is considered abnormal and is related to deviation of the microfibrils (microfibril angle) from the longitudinal axis of the tracheid (Koehler 1954).

Six types of wood are most susceptible to excessive longitudinal shrinkage: reaction wood, abnormally light wood, springwood, wood near the pith of softwood trees or juvenile wood, wood in fast-growth conifers, and cross-grained wood (Koehler 1954). In conifers, reaction wood (compression wood), juvenile wood, and cross grain have been associated with excessive lumber warpage (Cockrell 1949, Dadswell 1958, Koehler 1938, Meylan 1968, Meylan and Probine 1969, Paul 1957, Pillow and Luxford 1937, and Shelly et al. 1979). Recent literature on causes of warping of young-growth ponderosa pine include Barger and Ffolliott (1976), Voorhies (1971, 1972, 1982), and Voorhies and Groman 1982.

Research to reduce warpage of studs has focused on drying and sawing methods. Studs with a top load restraint of 200 pounds per square foot were air-dried, kiln-dried at conventional temperatures, and kiln-dried at high temperatures. The studs kiln-dried at conventional temperatures yielded the greatest number meeting grade requirements (Arganbright et al. 1978). Blake and Voorhies (1980) did not find any difference in grade recovery between drying schedules using conventional and high temperatures in kiln-drying studs from young-growth ponderosa pine. Koch (1974) found that a high temperature kiln schedule with load restraints reduced bow and twist; but, serrated stickers were needed to minimize crook in southern pine studs. Maeglin and Boone (1983) showed that the grade yield of studs from small ponderosa pine logs by the Saw-Dry-Rip method can be substantially increased, compared to conventional sawing and drying at sawmills.

Study Objectives

The overall objective of this study was to observe how warp in lumber from young growth ponderosa pine is related to growing site, tree and wood characteristics, and ultimate moisture content of the dried lumber.

Two of the study's specific objectives are reported here.

1. Estimate the effects of site class, tree diameter, log size and position in the tree, and moisture content specifications upon degrade and warp in studs after:
   a. Initial kiln drying to either 19% or 15% moisture content.
   b. Additional drying to 9% and 6% moisture content. The additional drying was to simulate the effects of subsequent drying on warp development during unrestrained storage and at the job site.
2. Determine if studs sawed from the top logs of larger trees degrade and warp differently than those of the same size logs from smaller trees.

Methods

Study Areas and Tree Selection

A total of 82 young growth, "black bark" ponderosa pine trees were sampled at two sites on the Santa Fe National Forest, in northern New Mexico. These trees were (visually) selected to be representative of those to be harvested in the area. One-half of the trees were selected from a low index site; the remainder were chosen from a high index site. The number of trees selected in each diameter class on each site were:

Diameter class	Number of trees
inches d.b.h.	
9	12
10	8
11	6
12	5
13	5
14	5

The trees on the low index site were collected from the top of Alamitos Mesa (T. 20N, R. 6E, Sec. 27), on the Espanola Ranger District. The area has a site index of 55, a slope of less than 5% exposed to the east, and a soil of thin pumice. The trees on the high index site were collected near the Mud Springs Road (T. 26N., R1E, S29), on the Cuba Ranger District. This area has a site index of 100. Characteristics of the sample trees are shown in table 1. All of the sawlogs were grade 5, typically having many live and dead branches, branch stubs, and overgrown branches (Gaines 1962).

Trees were selected and identified by numbering them. Diameter at breast height was measured and recorded, as were grade of the logs in the standing tree, and lean. The trees were felled, limbed, and measured for total height. Five trees for each diameter class, at each site were sampled for the microfibril angle determinations. One-inch disks were sawn from the bottom and top of the tree length log and a ½-inch diameter increment core was extracted from the mid-length. The tree length logs were skidded to a landing, were bucked into 8-foot lengths, and were tagged with a tree and log number. The Colorado State Forest Service sawed the logs into studs in Fort Collins. The logs were end coated with a commercial paraffin water repellent to prevent end drying during a two month storage period before sawing.

Sawing

The 293 logs were separated by small end diameter inside bark to facilitate sawing. Diameter groups were as follows:

Groups	Small-end d.i.b	
	Mean ± SD	Number of logs
	inches	
1	5.9 ± 0.5	53
2	7.1 ± 0.4	77
3	8.1 ± 0.4	56
4	9.0 ± 0.4	44
5	10.3 ± 0.6	58
6	12.1 ± 0.3	5

The logs were sawn using methods that followed industry practices. Log groups 1, 2, and 3 were sawn on a portable scragg mill, and groups 4, 5, and 6 on a circular sawmill, into 4-inch cants and 2-inch flitches. The four-saw scragg mill produced a 4-inch cant from the center and 2-inch flitches from the sides of the logs. The 4-inch cants were passed through a circular gang saw and were ripped into studs 2 inches wide. The 2-inch flitches were passed through the same circular gang saw and were ripped into studs 4 inches wide. The studs were identified as to tree and log number by spraying the log ends with different colored paints before sawing and by assigning a log number to each stud. The studs, after passing through the circular gang saw, were alternately stacked into four solid lumber piles to provide a uniform distribution of studs into 4 kiln charges. Each pile was wrapped with polyethylene film to prevent loss of moisture content before kiln drying.

Kiln Drying

The four piles of lumber were assigned numbers 1 through 4. Piles 1 and 3 were kiln dried to 19% moisture content (MC); piles 2 and 4 were kiln dried to 15% MC. These two moisture contents are standard specifications described by the Western Wood Products Association (1981). The standards state that any lumber surfaced at a moisture content of 19% or less may be stamped "S-DRY", and any lumber surfaced at a moisture content of 15% or less may be stamped "MC 15."

Table 1.—Characteristics of sample trees on low and high index sites.

Characteristics	Site	
	Low	High
	mean ± SD[1]	
Diameter (inches d.b.h.)	11.4 ± 1.9	11.4 ± 1.7
Total height (feet)	46.4 ± 6.3	59.4 ± 11.2
Height to 4-inch top d.i.b. (feet)	36.2 ± 6.8	47.4 ± 10.9
Height to 6-inch top d.i.b. (feet)	30.5 ± 7.3	39.5 ± 10.8
Volume, gross scale of logs (cubic feet)	10.8 ± 5.5	13.6 ± 7.0
No. of 8-foot logs per tree	3.1 ± 0.9	4.0 ± 1.2
Age at stump (years)	76 ± 19	78 ± 24
Lean (degrees)	2.2 ± 1.9	2.2 ± 1.9

[1]*Each mean and standard deviation is based on a sample of 41 trees.*

Each of the four kiln charges was dried following time schedule AS11-BK6 (Rasmussen 1961). Although commercial schedules vary from mill to mill, depending on kiln type and performance and lumber condition, this schedule closely approached the condition that many operators in the area were trying to achieve. This schedule follows.

Time	Temperature	
	Dry bulk	Wet bulb
hours	°F	
0-12	165	150
12-24	170	155
24-36	175	155
36-48	180	160
48-60	190	165
60-72	190	165
72-Final	200	170

The studs were dried in the Wood Science Laboratory kiln at Colorado State University (fig. 1). This kiln is steam heated and has two four-speed reversible fans and a capacity of approximately 2,000 board feet. The kiln is equipped with a Delmhorst Kil-Mo-Trol[2] which was used to monitor the charge and determine when to begin equalization. Because studs normally are not resawn, no conditioning treatment was included in the kiln runs. Equalizing was terminated when each of the six in-place meter probes gave a reading which was within 3% of the target moisture content. Equalizing conditions and times are shown in table 2. For all four charges, the average initial moisture contents were above fiber saturation point, based upon the initial meter readings.

After drying, the studs were planed on four sides, on a commercial planer, to standard 1 1/2-inch × 3 1/2-inch size. Then they were examined for lumber grade, crook, bow, twist, cup, grain angle, number of knots, size of largest knot, and end split.

[2]*Trade and company name are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture.*

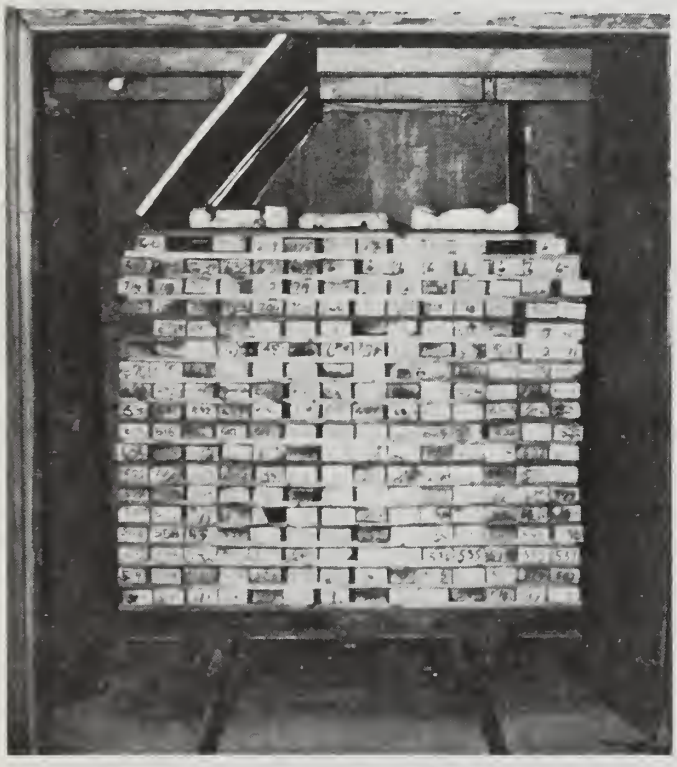

Figure 1.—Laboratory kiln with charge of stickered studs.

Subsequent Drying

Because much lumber produced in the Southwest is used in areas with low equilibrium moisture content condition, the studs were subsequently dried in two steps to 9% and then to 6% MC. At each of these moisture contents, the studs were regraded and measurements were taken for crook, bow, twist, cup, and end split. Kiln drying conditions were relatively mild (100°F dry bulb and 84°F wet bulb for 9%; 100°F dry bulb and 74°F wet bulb for 6%) in order to simulate conditions of lumber in storage or on a job site.

Also, as part of this simulation, the lumber was placed on a rack in the kiln, which allowed unrestricted shrinkage in each stud (fig. 2). Although in actual conditions, most of the lumber in a storage pile would be subject to some restraint, the conditions for this study were selected to give a "worst condition" situation. Attainment of the desired final moisture content was determined by a portable resistance-type moisture meter. Sample readings were taken periodically, and the drying was stopped when the readings were within 1% of the target moisture content.

Grading and Measurements

The studs were graded STUD, ECONOMY, or CULL, and the crook, bow, twist, cup, grain angle, size of largest knot, and end split were measured as defined by the Western Wood Products Association (1981). Crook is a deviation edgewise from a straight line drawn from end to end of the stud. It is measured at the greatest distance from the straight line. Bow is deviation flatwise from a straight line drawn from end to end and is measured at the point of greatest distance from the straight line. Twist is a deviation flatwise or a combination of flatwise and edgewise deviation in the form of a curl and is measured by clamping an end of the stud on a table and measuring the maximum distance that a lower corner at the other end is above the table. Cup is a deviation in the face of a piece from a straight line drawn from edge to edge and is measured as the greatest distance from the straight line. The width of the knot is measured as the distance between two lines touching the edge of the knot on the wide face and parallel to the edge of the stud. The slope of grain is determined with a scribe and is measured as the deviation of wood fiber on the wide face from a line parallel to the edges of the stud. End split is measured as the length of the split parallel to the edge of the stud.

Table 2.—Drying time, desired final moisture content (percent of oven-dry weight), and equalizing conditions of dry and wet bulb and time for the four kiln charges.

Charge	Drying time	Desired final moisture content	Equalizing conditions		
			Dry bulb	Wet bulb	Time
	hours		--------- °F ---------		*hours*
1	48	15	180	175	8
2	36	19	175	173	15
3	36	15	180	175	12
4	36	19	175	173	11

Analysis

The effects of growing site, tree diameter, log size and position, and extent of drying lumber grade were estimated using log linear models (Bishop et al. 1975). The effects of these variables upon amount of crook, bow, and twist after drying were determined by factorial analysis of variance. Because practical amounts of cup occurred in only a few studs during drying, it was omitted from the analysis. The term significant indicates statistical significance at the 0.05 level.

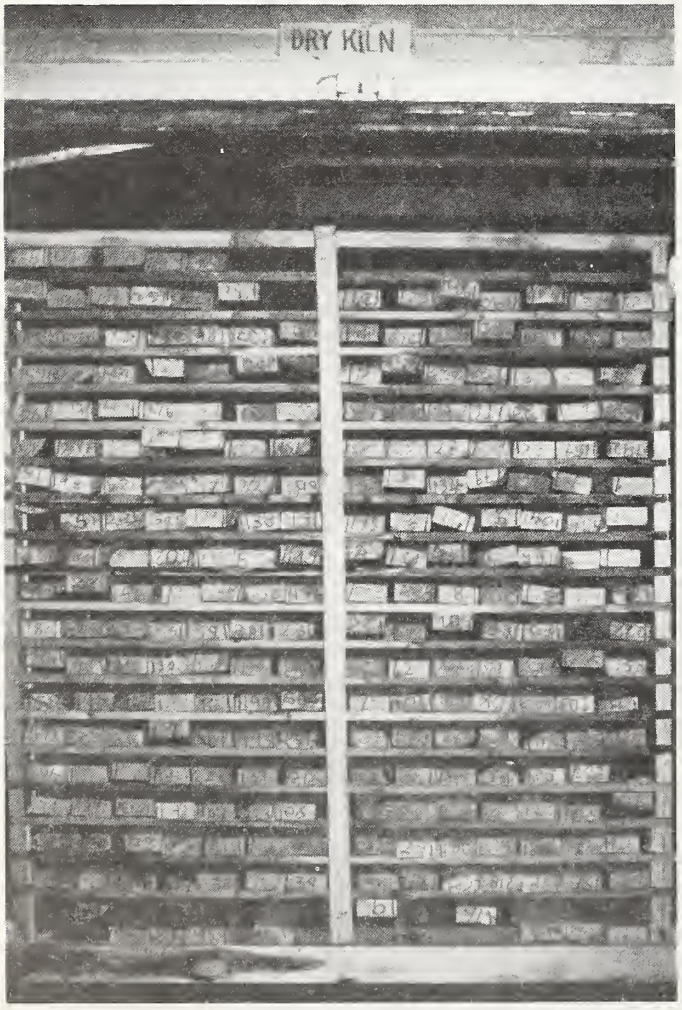

Figure 2.—Rack separating studs to permit unrestricted movement during drying to 9% and 6 % moisture content.

Results and Discussion

Growing Site

Site index was not significantly related to the percentage of studs in the different lumber grades or to the amount of crook, bow, and twist in the studs (table 3). When studs were dried from 19% or 15% moisture content (MC) to 9% and 6%, the grade of the lumber dropped. The proportion of STUD pieces dropped from 52% to 37% to 27%. The proportion of ECONOMY pieces increased from 48% to 54% to 56%; and cull increased from 0% to 9% to 17%.

When the studs were dried from 19% or 15% MC to 9% and 6%, the average crook increased from 4/16 to 5/16 to 6/16 inch, the average bow from 5/16 to 7/16 to 9/16 inch, and average twist from 4/16 to 6/16 to 7/16 inch.

Warpage varied considerably among both between and within categories. The similar values of average warp and percentage of studs in the different lumber grades between sites 55 and 100 may be partially attributed to the characteristics of the trees. As noted before, each log in the study regardless of site was a Grade 5 log. The logs had many limbs, limb stubs, and overgrown limbs.

Tree Diameter

Tree diameter did significantly affect the percentage of studs recovered in the different lumber grades and the amount of crook, bow, and twist in the studs. The percentage yield of lumber grade for trees 9, 10, and 11 inches d.b.h. was more adversely affected by further drying than that for trees with 12, 13, and 14 inches d.b.h. (table 4). The percentage of cull studs in the 9-, 10-, and 11-inch d.b.h. trees was significantly greater, about twice that of the 12-, 13-, and 14-inch d.b.h. trees when dried to 9% and 6% MC. The 9-inch d.b.h. trees had the lowest yield of STUD grade and the highest yield of cull studs after kiln drying and further drying. The 13-inch d.b.h. trees had the highest recovery of STUD grade studs.

Crook after kiln drying was similar for all tree diameters, with averages ranging from 4/16 to 5/16 inch. Average crook after further drying increased to a maximum of 7/16 inch at 9% MC for 11-inch d.b.h. trees and

Table 3.—Percentage of studs in each lumber grade and warp of studs sawn from trees sampled in areas with different site index and kiln dried to different moisture contents (percent of oven-dry weight).[1]

Moisture content	Site index	Lumber grade			Warp—1/16 inch		
		Stud	Economy	Cull	Crook	Bow	Twist
		percent			mean ± SD		
After kiln drying	55	52	48	0	4.1 ± 3.6	5.2 ± 4.6	3.6 ± 3.5
	100	52	48	0	4.2 ± 3.6	4.9 ± 4.2	4.0 ± 3.3
	combined	52	48	0	4.1 ± 3.6	5.0 ± 4.4	3.8 ± 3.4
9%	55	37	51	12	5.2 ± 5.1	7.0 ± 5.7	5.7 ± 5.0
	100	37	56	7	5.1 ± 5.2	6.9 ± 6.5	5.9 ± 4.4
	combined	37	54	9	5.1 ± 5.1	7.0 ± 6.2	5.8 ± 4.7
6%	55	28	53	19	6.6 ± 6.4	9.1 ± 7.6	6.8 ± 5.6
	100	27	59	14	6.1 ± 6.2	8.9 ± 8.0	7.0 ± 5.2
	combined	27	56	17	6.3 ± 6.3	9.0 ± 7.8	7.0 ± 5.4

[1]*The percentage values are based on 382 studs from 41 trees sampled in an area with site index 55 and 483 studs from 41 trees with site index 100.*

Table 4.—Percentage of studs in each lumber grade and warp of studs sawn from trees with different d.b.h. and kiln dried to different moisture contents (percent of oven-dry weight).[1]

Moisture content	Tree d.b.h.	Lumber grade			Warp—1/16 inch		
		Stud	Economy	Cull	Crook	Bow	Twist
	inches	percent			mean ± SD		
After kiln drying	9	39	61	0	3.9 ± 3.3	7.2 ± 5.1	5.1 ± 4.2
	10	51	49	0	4.3 ± 4.1	5.6 ± 4.9	3.8 ± 3.0
	11	47	53	0	4.9 ± 4.7	4.7 ± 3.8	3.9 ± 3.1
	12	53	47	0	3.6 ± 3.2	5.0 ± 4.8	3.9 ± 3.2
	13	62	38	0	3.8 ± 3.0	4.0 ± 3.6	3.5 ± 3.2
	14	54	46	0	4.4 ± 3.6	4.6 ± 3.9	3.5 ± 3.5
9%	9	19	60	21	5.3 ± 4.2	10.5 ± 6.9	7.7 ± 5.3
	10	32	59	9	5.9 ± 6.0	8.4 ± 6.2	5.8 ± 3.9
	11	24	62	14	6.8 ± 8.2	8.2 ± 8.8	6.0 ± 4.6
	12	38	57	5	4.4 ± 4.1	6.3 ± 5.3	6.0 ± 4.5
	13	52	41	7	4.2 ± 3.5	5.2 ± 4.8	5.1 ± 4.2
	14	42	51	7	5.2 ± 4.6	5.7 ± 4.6	5.3 ± 5.0
6%	9	12	53	35	6.3 ± 4.7	13.8 ± 8.6	8.7 ± 6.5
	10	27	52	21	8.0 ± 7.9	10.1 ± 8.3	6.9 ± 4.8
	11	15	61	24	8.4 ± 10.0	10.6 ± 9.7	7.3 ± 5.3
	12	30	59	11	5.3 ± 4.9	8.5 ± 7.1	7.2 ± 5.0
	13	38	50	12	5.2 ± 4.5	7.0 ± 6.7	6.5 ± 5.1
	14	30	61	9	6.0 ± 5.1	7.4 ± 5.9	6.1 ± 5.5

[1]*The number of studs sampled for each tree d.b.h. are: 9 inches—105, 10 inches—124, 11 inches—103, 12 inches—148, 13 inches—179, and 14 inches—206.*

8/16 inch at 6% MC for the 10- and 11-inch d.b.h. trees. Marketing limits for crook are 4/16 inch for STUD grade and 1 inch for ECONOMY grade (Western Wood Products Association 1981). There was no apparent trend relating the amount of crook to tree diameter. Crook varied considerably within each tree diameter class (table 4).

Average bow after kiln drying ranged from 4/16 to 7/16 inch with the 9-inch d.b.h. trees having the greatest amount. Average bow for the 9-inch d.b.h. trees after further drying increased to a maximum of 11/16 inch at 9% MC and 14/16 inch at 6%. Marketing limits for bow are 12/16 inch for STUD grade and none for ECONOMY grade (Western Wood Products Association 1981). Considerable variation of bow was observed within each tree diameter class.

Twist was similar to bow—the 9-inch d.b.h. trees had the greatest amount when compared to the other size trees. The average twist of the 9-inch d.b.h. trees ranged from 5/16 inch after kiln drying to 8/16 inch at 9% MC

and 9/16 inch at 6% MC. Marketing limits for twist are 6/16 inch for STUD grade and 1 inch for ECONOMY grade (Western Wood Products Association 1981). Twist also varied considerably within tree diameter class.

Moisture Content Specification

Drying studs with different moisture content specifications did not significantly affect the percentage of studs in the different lumber grades. Drying studs with different moisture content specifications also did not significantly affect the amount of crook, bow, and twist, when tree diameter was accounted for (tables 5, 6). The percentage recovery of lumber grade and warp measurements for the different combinations of moisture content specification, diameter, and log position are shown in tables A1 through A4.

Log Size and Position in Tree

Log position in the trees was not a significant indicator of lumber grade and warp when log diameter (d.i.b.) was accounted for. The 5- and 6-inch logs had a lower percentage of studs in STUD grade than the 7- through 12-inch logs after kiln drying (table 7). The 5- through 8-inch logs had a lower percentage of studs in STUD grade and a higher percentage of cull studs than the 9- through 12-inch logs after drying to 9% MC. Similarly, the 5-, 6-, and 7-inch logs had a lower percentage of studs in STUD grade and a higher percentage of cull studs than the 8- through 12-inch logs after drying to 6% MC.

A direct relationship of amount of crook with log diameter was not apparent (table 7). Generally, the 5- through 8-inch logs had more bow than the 9- through 12-inch logs after each drying condition. Similarly, the 5-, 6-, and 7-inch logs had more twist than the 8- through 12-inch logs. Research on young growth ponderosa pine has shown that butt logs have more crook and less twist than upper logs (Blake and Voorhies 1980, Maeglin and Boone 1983).

A separate analysis was performed to determine if studs from small logs of big trees warped differently than those from small logs of small trees. Analysis of 263 studs from logs of 8-inch d.i.b. and less indicated that:

1. The percentage of studs in each lumber grade is affected by moisture content, but is unrelated to tree size (diameter breast high) after kiln drying (table 8).
2. The studs from smaller trees did not warp more than those from the larger trees (table 8).

Conclusion

The results of this study indicate that a difference in site index from 55 to 100 for young growth "black jack" ponderosa pine does not affect either the grade or the amount of crook, bow, and twist of lumber kiln dried to commercial moisture specifications (S-DRY or MC15) and further dried to 9% and 6% MC. Tree diameter, however, does affect lumber grade recovery; 9-inch

Table 5.—Percentage of studs in each lumber grade and warp of studs sawn from trees with different d.b.h. and kiln dried to S-DRY specification and subsequently dried to 9% and 6% moisture content (percent of oven-dry weight).[1]

Moisture content	Tree d.b.h.	Lumber grade			Warp—1/16 inch		
		Stud	Econ	Cull	Crook	Bow	Twist
	inches	------- *percent* -------			---------- *mean ± SD* ----------		
After kiln drying	9	38	62	0	4.1 ± 3.3	7.4 ± 5.5	5.2 ± 4.6
	10	58	42	0	4.6 ± 5.0	4.8 ± 4.1	3.8 ± 3.0
	11	47	53	0	4.7 ± 5.3	4.8 ± 4.0	4.2 ± 3.2
	12	63	37	0	3.0 ± 2.5	4.4 ± 4.6	3.3 ± 2.8
	13	63	37	0	3.3 ± 2.7	3.8 ± 3.4	3.6 ± 3.1
	14	60	40	0	3.9 ± 3.1	4.2 ± 3.4	3.7 ± 3.6
9%	9	21	62	17	5.8 ± 4.7	10.2 ± 6.1	7.9 ± 5.9
	10	31	61	8	6.5 ± 7.4	8.8 ± 6.0	6.1 ± 4.0
	11	20	65	15	7.5 ± 10.7	7.8 ± 4.9	6.9 ± 5.4
	12	40	56	4	3.9 ± 2.9	6.7 ± 5.6	5.5 ± 4.2
	13	52	40	8	4.2 ± 3.8	6.0 ± 5.6	5.5 ± 4.7
	14	43	47	10	5.1 ± 5.3	5.9 ± 4.7	5.9 ± 5.5
6%	9	11	57	32	7.0 ± 5.3	15.1 ± 8.2	9.3 ± 7.5
	10	24	55	21	9.5 ± 9.7	11.0 ± 8.3	7.5 ± 5.2
	11	6	65	29	10.7 ± 12.8	11.2 ± 6.9	8.7 ± 6.0
	12	29	63	8	5.4 ± 3.7	9.5 ± 7.9	6.9 ± 5.0
	13	29	56	15	6.0 ± 5.2	8.5 ± 8.1	7.1 ± 5.3
	14	23	63	14	6.5 ± 6.0	8.3 ± 6.1	6.9 ± 6.3

[1]*The number of studs sampled for each tree d.b.h. are: 9 inches—47, 10 inches—67, 11 inches—51, 12 inches—75, 13 inches—88, and 14 inches—100.*

Table 6.—Percentage of studs in each lumber grade and warp of studs sawn from trees with different d.b.h. and kiln dried to MC-15 specification and subsequently dried to 9% and 6% moisture content (percent of oven-dry weight).[1]

Moisture content	Tree d.b.h.	Lumber grade			Warp—1/16 inch		
		Stud	Econ	Cull	Crook	Bow	Twist
	inches	*percent*			*mean ± SD*		
After kiln drying	9	40	60	0	3.8 ± 3.3	7.0 ± 4.8	4.9 ± 3.8
	10	42	58	0	3.9 ± 2.8	6.6 ± 5.5	3.8 ± 3.1
	11	46	54	0	5.2 ± 4.0	4.5 ± 3.7	3.7 ± 3.0
	12	43	57	0	4.3 ± 3.6	5.6 ± 5.0	4.4 ± 3.4
	13	60	40	0	4.1 ± 3.2	4.1 ± 3.7	3.5 ± 3.3
	14	48	52	0	4.9 ± 4.0	4.9 ± 4.2	3.3 ± 3.4
9%	9	17	59	24	5.0 ± 3.8	10.8 ± 7.6	7.5 ± 4.8
	10	33	56	11	5.1 ± 3.7	7.8 ± 6.4	5.4 ± 3.8
	11	29	59	12	6.0 ± 4.6	8.6 ± 11.4	5.0 ± 3.5
	12	36	59	5	4.9 ± 5.0	5.8 ± 5.1	6.5 ± 4.7
	13	52	42	6	4.1 ± 3.2	4.5 ± 3.8	4.8 ± 3.8
	14	41	54	5	5.2 ± 3.8	5.5 ± 4.5	4.7 ± 4.4
6%	9	14	48	38	5.7 ± 4.2	12.7 ± 8.7	8.2 ± 5.6
	10	30	49	21	6.3 ± 4.4	9.1 ± 8.2	6.3 ± 4.4
	11	23	58	19	6.2 ± 5.3	9.9 ± 11.8	5.8 ± 4.1
	12	30	56	14	5.2 ± 5.8	7.4 ± 6.1	7.6 ± 5.1
	13	47	44	9	4.3 ± 3.6	5.5 ± 4.7	6.0 ± 4.8
	14	37	58	5	5.6 ± 4.1	6.5 ± 5.6	5.3 ± 4.5

[1]*The number of studs sampled for each tree d.b.h. are: 9 inches—58, 10 inches—57, 11 inches—52, 12 inches—73, 13 inches—91, and 14 inches—106.*

Table 7.—Percentage of studs in each lumber grade and warp of studs sawn from logs with different d.i.b. and kiln dried and subsequently dried to 9% and 6% moisture content (percent of oven-dry weight).[1]

Moisture content	Log d.i.b. small end	Lumber grade			Warp—1/16 inch		
		Stud	Econ	Cull	Crook	Bow	Twist
	inches	*percent*			*mean ± SD*		
After kiln drying	5	27	73	0	3.8 ± 2.8	8.4 ± 5.6	6.1 ± 4.8
	6	38	62	0	3.7 ± 3.1	6.4 ± 4.5	5.1 ± 3.6
	7	48	52	0	4.3 ± 3.4	5.8 ± 4.8	4.4 ± 3.6
	8	50	50	0	4.7 ± 4.6	4.8 ± 3.8	3.5 ± 3.0
	9	60	40	0	4.0 ± 3.6	4.1 ± 4.1	3.3 ± 3.0
	10	63	37	0	3.7 ± 2.6	4.3 ± 4.1	3.3 ± 3.3
	11	54	46	0	4.4 ± 4.1	4.1 ± 3.9	3.6 ± 3.0
	12	50	50	0	4.3 ± 2.7	5.2 ± 4.3	2.5 ± 2.5
9%	5	6	70	24	6.2 ± 3.0	12.0 ± 4.9	10.0 ± 5.4
	6	21	62	17	4.6 ± 3.6	9.7 ± 6.7	7.3 ± 5.0
	7	26	62	13	5.6 ± 4.8	8.4 ± 6.6	6.6 ± 4.8
	8	32	61	7	5.8 ± 5.7	7.3 ± 5.4	5.9 ± 4.5
	9	50	42	8	4.7 ± 6.3	5.2 ± 6.6	4.9 ± 4.1
	10	54	42	4	4.3 ± 3.8	5.1 ± 4.9	4.8 ± 4.5
	11	41	51	8	4.9 ± 4.0	6.0 ± 5.0	5.0 ± 3.7
	12	39	54	7	6.8 ± 7.1	6.3 ± 5.2	4.6 ± 4.2
6%	5	3	52	45	6.8 ± 3.9	15.0 ± 7.9	11.5 ± 6.8
	6	13	62	25	5.9 ± 4.4	12.3 ± 8.4	8.4 ± 6.0
	7	16	57	27	7.3 ± 6.5	10.6 ± 8.2	7.9 ± 5.2
	8	28	56	16	7.3 ± 7.4	9.2 ± 7.0	7.3 ± 5.6
	9	36	53	11	5.8 ± 7.0	7.0 ± 8.0	6.0 ± 4.6
	10	41	53	6	4.6 ± 4.0	6.9 ± 6.8	5.8 ± 5.3
	11	29	64	7	5.8 ± 4.1	7.6 ± 6.7	6.0 ± 4.2
	12	25	61	14	8.8 ± 9.3	6.9 ± 5.2	5.0 ± 4.2

[1]*The number of studs sampled for each log d.i.b. are: 5 inches—33, 6 inches—76, 7 inches—143, 8 inches—180, 9 inches—181, 10 inches—141, 11 inches—83, and 12 inches—28.*

Table 8.—Percentage of studs in each lumber grade and warp of studs sawn from logs of 8-inch diameter or less from trees with different d.b.h. and kiln dried to different moisture contents (percent of oven-dry weight).[1]

Moisture content	Tree d.b.h.	Lumber grade			Warp—1/16 inch		
		Stud	Econ	Cull	Crook	Bow	Twist
	inches	*percent*			*mean ± SD*		
After kiln drying	9	41	59	0	3.9 ± 3.3	7.1 ± 5.1	5.0 ± 4.2
	10	43	57	0	3.9 ± 3.2	6.0 ± 5.1	4.2 ± 3.3
	11	50	50	0	3.9 ± 2.9	5.1 ± 3.9	4.9 ± 3.1
	12	44	56	0	3.0 ± 2.5	6.6 ± 4.8	5.4 ± 3.0
	13	42	58	0	4.1 ± 3.0	4.8 ± 4.1	5.6 ± 4.0
	14	25	75	0	6.7 ± 4.1	6.8 ± 3.8	6.3 ± 5.4
9%	9	20	58	22	5.4 ± 4.3	10.3 ± 6.7	7.5 ± 5.3
	10	23	68	9	5.2 ± 4.3	8.7 ± 6.1	6.3 ± 4.0
	11	25	62	13	5.9 ± 5.1	8.7 ± 8.3	7.2 ± 4.7
	12	15	78	7	3.4 ± 2.4	9.1 ± 5.7	7.6 ± 4.2
	13	32	47	21	5.0 ± 4.0	7.2 ± 5.3	8.8 ± 6.3
	14	6	69	25	5.2 ± 4.4	9.1 ± 6.3	9.3 ± 8.1
6%	9	13	53	34	6.4 ± 4.8	13.6 ± 8.5	8.3 ± 6.2
	10	21	56	23	7.3 ± 5.8	10.4 ± 8.2	7.8 ± 4.9
	11	9	63	28	6.8 ± 7.7	10.3 ± 9.2	8.6 ± 4.9
	12	4	74	22	5.3 ± 3.4	12.1 ± 6.5	9.4 ± 4.0
	13	16	53	31	7.7 ± 7.6	10.3 ± 7.4	11.1 ± 6.6
	14	6	63	31	9.1 ± 4.7	11.3 ± 8.7	9.4 ± 8.2

[1]*The number of studs sampled for each tree d.b.h. are: 9 inches—101, 10 inches—68, 11 inches—32, 12 inches—27, 13 inches—19, and 14 inches—16.*

d.b.h. trees had the lowest grade recovery, and the 9-, 10-, and 11-inch d.b.h. trees yielded about twice the percentage of cull studs as the 12-, 13-, and 14-inch d.b.h. trees when dried to 9% and 6% MC. Lumber from 9-inch d.b.h. trees also bowed and twisted most during the different stages of drying.

Log position in the tree had little effect on lumber grade recovery and warp when log diameter was accounted for. The smaller logs yielded lower grade lumber with generally more warp than the larger logs. Kiln drying to either the S-DRY or MC15 specification did not affect the grade or lumber recovered or the amount of warp when tree diameter was accounted for.

The claim that studs from small top logs of larger trees do not lose grade or warp as much as those from small logs of smaller trees was not supported by the results of this study. The studs from logs 8 inches or less in diameter, regardless of location in the tree, had similar grades and warpage, and were affected only by moisture content.

The study indicates that growing young "black jack" ponderosa pine trees to a diameter greater than 11 inches would reduce the warpage of studs marketed in low humidity areas.

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Appendix

Tables on Percentage of Lumber Grade and Warp Measurements for Different Combinations of Moisture Content Specification, Diameter Breast Height and Log Position

Table A1.—Percentage of studs in each lumber grade sawn from trees with different d.b.h. and at different log positions and kiln dried to MC-15 specification and subsequently dried to 9% and 6% (percent of oven-dry weight).

Tree d.b.h.	Log position	Lumber grade at moisture content of: After kiln drying			9%			6%			No. of studs
		Stud	Econ	Cull	Stud	Econ	Cull	Stud	Econ	Cull	
inches		*percent*									
9	1	32	68	0	18	55	27	9	50	41	22
	2	50	50	0	21	58	21	21	50	29	24
	3	40	60	0	10	70	10	10	50	40	10
	4	0	100	0	0	50	50	0	0	100	2
10	1	60	40	0	48	48	4	40	52	8	25
	2	57	43	0	43	57	0	43	43	14	14
	3	7	93	0	7	64	29	7	50	43	14
	4	0	100	0	0	67	33	0	33	67	3
	5	0	100	0	0	100	0	0	100	0	1
11	1	43	57	0	29	47	24	19	52	29	21
	2	48	52	0	33	67	0	29	62	9	21
	3	57	43	0	29	71	0	14	72	14	7
	4	33	67	0	0	67	33	33	33	34	3
12	1	48	52	0	48	48	4	44	44	12	25
	2	33	67	0	33	67	0	22	61	17	18
	3	35	65	0	35	53	12	29	59	12	17
	4	71	29	0	14	86	0	14	71	15	7
	5	0	100	0	0	67	33	0	67	33	3
	6	100	0	0	50	50	0	50	50	0	2
	7	0	100	0	0	100	0	0	100	0	1
13	1	68	32	0	55	45	0	59	41	0	22
	2	58	42	0	38	54	8	38	54	8	24
	3	63	37	0	71	25	4	58	34	8	24
	4	53	47	0	47	40	13	40	40	20	15
	5	50	50	0	33	67	0	17	66	17	6
	6	–	–	–	–	–	–	–	–	–	0
14	1	50	50	0	45	55	0	42	55	3	39
	2	45	55	0	38	52	10	35	55	10	29
	3	63	37	0	63	37	0	56	44	0	16
	4	35	65	0	29	65	6	18	82	0	17
	5	60	40	0	20	80	0	20	80	0	5
	6	0	0	0	0	0	0	0	0	0	0

Table A2.—Percentage of studs in each lumber grade sawn from trees with different d.b.h. and at different log positions, kiln dried to S-DRY specification and subsequently dried to 9% and 6% (percent of oven-dry weight).

Tree d.b.h.	Log position	Lumber grade at moisture content of: After kiln drying			9%			6%			No. of studs
		Stud	Econ	Cull	Stud	Econ	Cull	Stud	Econ	Cull	
inches		*percent*									
9	1	29	71	0	18	59	23	12	41	47	17
	2	41	59	0	35	47	18	12	65	23	17
	3	46	54	0	8	85	7	8	69	23	13
	4	–	–	–	–	–	–	–	–	–	0
10	1	65	35	0	27	62	11	15	58	27	26
	2	61	39	0	48	43	9	39	44	17	23
	3	36	64	0	18	82	0	18	64	18	11
	4	60	40	0	20	80	0	20	80	0	5
	5	50	50	0	0	100	0	0	50	50	2
11	1	40	60	0	15	60	25	5	60	35	21
	2	62	38	0	15	77	8	0	77	23	14
	3	55	45	0	27	55	18	18	46	36	11
	4	20	80	0	40	60	0	0	80	20	5
12	1	71	29	0	48	52	0	38	62	0	21
	2	73	27	0	50	46	4	36	59	5	22
	3	56	44	0	39	50	11	33	44	23	18
	4	43	57	0	14	86	0	0	86	14	7
	5	50	50	0	17	83	0	0	100	0	6
	6	–	–	–	–	–	–	–	–	–	0
	7	0	100	0	0	100	0	0	100	0	1
13	1	64	36	0	60	32	8	28	60	12	25
	2	80	20	0	68	24	8	36	52	12	25
	3	63	37	0	44	56	0	44	50	6	16
	4	47	53	0	40	47	13	13	67	20	15
	5	17	83	0	17	66	17	17	33	50	6
	6	100	0	0	0	100	0	0	100	0	1
14	1	63	37	0	42	47	11	16	71	13	37
	2	63	37	0	54	37	8	29	63	8	24
	3	60	40	0	50	45	5	35	60	5	20
	4	64	36	0	27	64	9	18	55	27	11
	5	50	50	0	25	75	0	25	50	25	4
	6	0	100	0	0	25	75	0	25	75	4

Table A3.—Warp of studs sawn from trees with different d.b.h. and at different log position, kiln dried to MC-15 specification, and subsequently dried to 9% and 6% moisture content (percent of oven-dry weight).

Tree d.b.h.	Log position	Warp -1/16 inch at moisture content of: After kiln drying			9%			6%			No. of studs
		Crook	Bow	Twist	Crook	Bow	Twist	Crook	Bow	Twist	
inches		*mean ± SD*									
9	1	4.5 ± 4.4	7.1 ± 5.5	3.8 ± 3.9	5.6 ± 4.9	12.0 ± 8.3	6.1 ± 5.1	7.0 ± 5.3	14.0 ± 8.9	6.8 ± 5.2	22
	2	3.0 ± 2.1	6.2 ± 3.9	5.0 ± 2.5	3.9 ± 2.7	9.5 ± 7.1	7.5 ± 3.5	4.5 ± 3.1	11.2 ± 7.7	7.9 ± 4.4	24
	3	3.9 ± 2.6	7.6 ± 5.3	6.7 ± 5.3	5.3 ± 2.8	10.8 ± 7.8	9.1 ± 5.1	5.3 ± 2.7	14.0 ± 11.2	10.5 ± 5.6	10
	4	6.0 ± 2.8	11.0 ± 1.4	8.0 ± 5.7	9.0 ± 4.2	11.5 ± 6.4	15.5 ± 4.9	9.5 ± 6.4	11.0 ± 9.9	17.0 ± 15.6	2
10	1	3.8 ± 2.5	4.8 ± 4.6	1.9 ± 1.5	4.4 ± 3.2	6.4 ± 4.6	3.6 ± 2.8	5.0 ± 3.2	7.9 ± 7.1	3.9 ± 2.3	25
	2	4.3 ± 3.6	5.6 ± 4.7	3.1 ± 2.5	5.4 ± 4.4	6.0 ± 4.7	4.6 ± 3.3	6.1 ± 4.7	7.2 ± 6.5	5.9 ± 4.2	14
	3	3.6 ± 2.5	10.2 ± 6.2	7.0 ± 2.5	5.6 ± 3.6	11.4 ± 8.8	9.1 ± 3.1	7.4 ± 4.7	13.4 ± 10.5	10.9 ± 3.0	14
	4	2.7 ± 1.2	10.7 ± 6.1	8.0 ± 4.0	6.7 ± 4.6	12.0 ± 8.0	8.0 ± 4.0	12.0 ± 8.0	8.7 ± 9.9	8.0 ± 8.0	3
	5	8.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	7.0 ± 0.0	6.0 ± 0.0	0.0 ± 0.0	7.0 ± 0.0	3.0 ± 0.0	2.0 ± 0.0	1
11	1	5.9 ± 4.7	4.2 ± 3.7	3.1 ± 2.7	6.4 ± 4.6	10.1 ± 17.1	4.2 ± 2.1	7.3 ± 4.7	13.0 ± 17.0	5.1 ± 2.9	21
	2	5.3 ± 4.0	4.4 ± 3.6	3.1 ± 2.8	6.3 ± 5.0	7.0 ± 4.1	4.4 ± 3.4	6.7 ± 6.2	7.9 ± 6.0	5.5 ± 3.8	21
	3	4.3 ± 1.0	5.1 ± 3.6	5.1 ± 3.0	4.7 ± 4.4	9.7 ± 6.8	6.6 ± 4.3	3.7 ± 4.1	9.0 ± 6.4	7.3 ± 5.2	7
	4	2.0 ± 0.0	5.3 ± 6.1	7.3 ± 4.2	3.7 ± 2.1	5.7 ± 2.1	10.7 ± 6.4	1.7 ± 1.5	5.3 ± 6.1	10.0 ± 8.7	3
12	1	3.6 ± 3.1	5.6 ± 5.9	4.1 ± 3.8	4.8 ± 5.5	5.0 ± 5.7	5.7 ± 5.0	4.8 ± 6.8	6.3 ± 7.0	7.1 ± 5.6	25
	2	6.2 ± 5.3	4.9 ± 4.1	3.6 ± 3.1	5.4 ± 6.7	5.4 ± 4.3	5.3 ± 4.5	6.4 ± 7.7	7.2 ± 5.7	6.6 ± 3.9	18
	3	3.6 ± 1.7	5.5 ± 4.8	4.8 ± 3.4	4.8 ± 3.1	6.0 ± 4.5	7.5 ± 4.6	4.5 ± 3.1	6.7 ± 5.5	8.5 ± 5.9	17
	4	4.0 ± 2.8	4.6 ± 4.1	5.0 ± 3.3	5.6 ± 5.0	7.5 ± 4.3	7.3 ± 4.0	5.1 ± 3.8	9.9 ± 4.7	8.3 ± 5.1	7
	5	4.7 ± 3.1	11.7 ± 3.2	7.0 ± 3.6	4.7 ± 1.2	12.7 ± 7.0	10.7 ± 5.1	5.7 ± 2.1	14.0 ± 7.2	10.0 ± 5.3	3
	6	1.5 ± 0.7	5.0 ± 4.2	6.0 ± 0.0	3.0 ± 1.4	2.0 ± 0.0	9.0 ± 4.2	4.0 ± 0.0	9.0 ± 4.2	10.0 ± 5.7	2
	7	0.0 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	4.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	2.0 ± 0.0	10.0 ± 0.0	6.0 ± 0.0	1
13	1	3.9 ± 2.1	3.4 ± 3.2	2.4 ± 2.5	3.6 ± 2.0	4.2 ± 3.2	3.6 ± 2.8	3.6 ± 2.2	3.9 ± 3.3	4.1 ± 3.2	22
	2	4.0 ± 2.0	4.8 ± 3.6	3.9 ± 2.6	4.5 ± 2.3	4.4 ± 3.4	4.9 ± 3.2	4.3 ± 2.4	6.2 ± 4.6	5.9 ± 3.3	24
	3	4.4 ± 2.9	3.1 ± 2.7	3.1 ± 3.0	3.8 ± 2.7	3.4 ± 3.0	4.0 ± 3.5	4.5 ± 3.4	4.7 ± 4.3	5.8 ± 5.5	24
	4	4.3 ± 5.9	5.4 ± 5.4	4.1 ± 3.8	4.9 ± 5.8	6.5 ± 5.3	6.5 ± 4.6	5.0 ± 6.5	8.1 ± 6.5	8.0 ± 5.7	15
	5	4.0 ± 3.5	5.2 ± 4.0	5.5 ± 6.3	3.8 ± 3.1	5.0 ± 3.9	7.5 ± 6.1	4.5 ± 3.3	4.7 ± 3.5	9.0 ± 7.3	6
	6	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	0
14	1	4.5 ± 3.4	5.3 ± 4.4	3.2 ± 2.8	5.5 ± 4.1	6.4 ± 4.7	4.4 ± 3.7	5.8 ± 4.5	7.8 ± 5.5	5.3 ± 3.8	39
	2	5.2 ± 5.5	4.7 ± 4.5	3.3 ± 3.8	4.9 ± 4.1	4.8 ± 4.5	4.8 ± 4.7	5.6 ± 4.3	5.6 ± 5.4	5.7 ± 5.6	29
	3	3.4 ± 1.8	4.0 ± 2.9	3.1 ± 3.5	3.9 ± 2.4	4.8 ± 3.6	4.4 ± 5.1	3.9 ± 2.3	4.6 ± 4.5	4.4 ± 3.9	16
	4	5.7 ± 3.0	4.5 ± 3.9	3.6 ± 3.5	6.1 ± 3.2	4.3 ± 3.5	5.5 ± 4.8	6.5 ± 3.6	4.8 ± 4.1	5.4 ± 4.4	17
	5	7.0 ± 6.0	6.4 ± 6.2	4.2 ± 4.9	5.2 ± 4.1	7.4 ± 6.2	5.8 ± 4.4	5.2 ± 2.4	9.8 ± 7.0	6.2 ± 4.5	5
	6	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	0

Table A4.—Warp of studs sawn from trees with different d.b.h. and at different log position, kiln dried to S-DRY specification, and subsequently dried to 9% and 6% moisture content (percent of oven-dry weight).

Tree d.b.h.	Log position	Warp -1/16 inch at moisture content of									No. of studs
		After kiln drying			9%			6%			
		Crook	Bow	Twist	Crook	Bow	Twist	Crook	Bow	Twist	
inches		*mean ± SD*									
9	1	5.4 ± 4.0	10.6 ± 6.0	4.5 ± 2.9	7.0 ± 6.6	12.4 ± 7.8	6.4 ± 5.1	8.8 ± 7.3	19.2 ± 8.6	8.4 ± 8.1	17
	2	3.3 ± 3.1	5.0 ± 3.8	5.3 ± 4.8	4.4 ± 3.2	8.0 ± 4.4	8.1 ± 6.3	6.2 ± 3.6	10.0 ± 5.7	8.8 ± 6.6	17
	3	3.5 ± 1.9	6.3 ± 4.8	6.2 ± 6.1	5.9 ± 2.8	10.2 ± 4.6	9.6 ± 6.4	5.9 ± 3.4	16.2 ± 7.4	11.2 ± 8.2	13
	4	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	0
10	1	5.0 ± 6.6	4.9 ± 4.5	3.8 ± 2.7	8.9 ± 10.0	10.2 ± 6.9	5.8 ± 4.0	12.7 ± 12.8	13.5 ± 9.3	7.7 ± 5.1	26
	2	4.1 ± 4.0	4.7 ± 4.2	3.4 ± 3.1	4.7 ± 5.2	7.3 ± 5.9	5.4 ± 3.8	7.5 ± 7.2	8.3 ± 8.4	6.3 ± 4.5	23
	3	5.2 ± 3.7	5.3 ± 4.3	4.8 ± 4.1	5.9 ± 5.0	8.1 ± 4.2	6.7 ± 4.0	7.5 ± 6.9	10.3 ± 4.8	7.7 ± 5.5	11
	4	2.4 ± 2.6	4.8 ± 2.4	3.4 ± 1.7	5.0 ± 2.0	11.8 ± 5.1	8.2 ± 3.3	7.8 ± 3.3	12.6 ± 8.0	10.4 ± 3.8	5
	5	6.5 ± 3.5	2.0 ± 0.0	4.0 ± 2.8	4.0 ± 2.8	6.5 ± 2.1	7.5 ± 7.8	6.5 ± 6.4	7.0 ± 1.4	10.0 ± 14.1	2
11	1	6.0 ± 7.4	4.7 ± 3.8	3.1 ± 2.3	9.9 ± 15.9	8.7 ± 4.8	5.2 ± 4.8	14.3 ± 17.8	12.0 ± 6.7	6.4 ± 5.1	21
	2	4.0 ± 3.1	4.5 ± 3.8	4.8 ± 3.6	6.4 ± 4.6	7.3 ± 4.5	9.9 ± 6.1	9.0 ± 5.8	12.4 ± 7.0	12.4 ± 6.0	14
	3	4.3 ± 3.8	4.3 ± 2.8	5.1 ± 3.7	7.0 ± 6.6	7.9 ± 6.3	7.0 ± 5.0	10.0 ± 10.5	10.2 ± 8.2	9.2 ± 6.1	11
	4	2.4 ± 0.9	4.6 ± 2.5	4.2 ± 3.9	3.0 ± 1.7	4.2 ± 2.5	5.8 ± 6.0	3.6 ± 3.3	5.8 ± 2.7	6.4 ± 7.1	5
12	1	3.0 ± 1.8	4.9 ± 5.7	2.2 ± 2.7	4.0 ± 2.9	7.2 ± 6.7	3.2 ± 3.2	5.1 ± 3.5	10.3 ± 10.3	3.6 ± 3.7	21
	2	2.5 ± 2.5	3.1 ± 3.6	3.1 ± 2.9	3.8 ± 2.8	4.7 ± 4.3	5.5 ± 4.0	5.2 ± 4.2	7.0 ± 5.7	6.7 ± 4.7	22
	3	2.6 ± 2.2	4.4 ± 4.5	4.3 ± 3.0	3.9 ± 2.8	7.2 ± 5.5	7.6 ± 5.1	5.9 ± 3.6	9.7 ± 6.6	9.9 ± 5.3	18
	4	4.6 ± 3.6	4.1 ± 4.3	2.9 ± 1.7	5.3 ± 4.5	5.7 ± 3.1	5.4 ± 4.1	7.3 ± 4.7	9.1 ± 6.9	8.3 ± 5.1	7
	5	4.5 ± 4.1	7.3 ± 4.1	4.5 ± 2.8	2.0 ± 1.8	11.5 ± 6.9	6.7 ± 3.1	3.7 ± 1.5	15.0 ± 8.6	8.7 ± 2.7	6
	6	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	-- ± --	0
	7	2.0 ± 0.0	8.0 ± 0.0	6.0 ± 0.0	4.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	14.0 ± 0.0	8.0 ± 0.0	1
13	1	3.0 ± 2.0	3.7 ± 3.3	3.4 ± 3.4	3.0 ± 2.4	6.1 ± 6.9	4.4 ± 4.0	4.9 ± 2.4	8.4 ± 9.4	5.8 ± 4.3	25
	2	3.0 ± 2.9	2.8 ± 3.5	3.0 ± 2.9	4.8 ± 5.0	5.0 ± 5.9	4.8 ± 4.1	5.0 ± 4.4	7.0 ± 8.6	6.4 ± 4.7	25
	3	3.0 ± 2.3	3.3 ± 1.4	2.5 ± 1.9	3.3 ± 2.1	5.3 ± 3.3	4.3 ± 4.3	4.7 ± 2.5	7.5 ± 6.2	5.9 ± 5.5	16
	4	3.7 ± 3.1	5.9 ± 4.1	5.4 ± 3.4	5.2 ± 4.6	6.1 ± 3.6	7.7 ± 5.2	8.9 ± 8.9	10.0 ± 6.2	9.8 ± 5.3	15
	5	6.3 ± 3.6	4.3 ± 3.9	5.5 ± 3.2	7.0 ± 3.8	10.0 ± 6.6	9.7 ± 6.4	11.1 ± 5.9	12.7 ± 8.7	11.7 ± 7.1	6
	6	3.0 ± 0.0	5.0 ± 0.0	3.0 ± 0.0	4.0 ± 0.0	16.0 ± 0.0	9.0 ± 0.0	6.0 ± 0.0	17.0 ± 0.0	10.0 ± 0.0	1
14	1	3.7 ± 2.9	3.9 ± 3.7	2.6 ± 2.3	6.0 ± 6.9	6.5 ± 4.8	4.8 ± 3.4	8.1 ± 8.6	8.3 ± 6.0	5.5 ± 3.7	37
	2	4.0 ± 3.0	4.1 ± 3.4	3.5 ± 3.3	4.4 ± 3.5	5.4 ± 4.1	5.0 ± 5.8	4.8 ± 2.4	7.4 ± 5.7	6.6 ± 7.1	24
	3	3.2 ± 2.4	3.9 ± 3.5	3.9 ± 3.9	3.5 ± 3.2	4.5 ± 4.2	5.9 ± 5.2	4.8 ± 3.0	6.9 ± 5.3	6.2 ± 5.8	20
	4	5.6 ± 4.1	4.1 ± 2.8	5.3 ± 4.8	6.3 ± 4.8	5.5 ± 3.7	9.3 ± 8.4	7.5 ± 4.6	9.3 ± 5.5	10.2 ± 9.1	11
	5	4.3 ± 5.2	5.7 ± 2.1	5.2 ± 2.2	5.8 ± 6.8	5.8 ± 2.1	7.7 ± 3.1	6.5 ± 5.3	8.5 ± 2.5	11.0 ± 6.2	4
	6	5.3 ± 2.8	8.3 ± 2.9	6.8 ± 7.3	6.5 ± 5.0	15.0 ± 8.2	9.8 ± 10.1	9.5 ± 5.5	21.0 ± 10.0	11.0 ± 11.6	4

Markstrom, Donald C., Craig E. Shuler, and Rudy M. King. 1984. Warpage of studs from young growth ponderosa pine from Northern New Mexico. USDA Forest Service Research Paper RM-257, 13 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Lumber grade recovery and warp of studs from young ponderosa pine trees are affected by tree diameter, but not by a difference in site index from 55 to 100 or log position in the tree. Trees 9 inches d.b.h. yielded lower grade studs with more warp than 10- through 14-inch d.b.h. trees. Logs 5-7 inches d.i.b. yielded lower grade lumber with more warp than 8- to 12-inch logs after drying to 6% moisture content. Subsequent drying simulating on-site 19% would not lessen warpage problems. Logs smaller than 8 inches d.i.b. from trees ranging from 9 to 14 inches d.b.h. produced lumber of similar grade and warpage.

Keywords: Warpage, forest products, *Pinus ponderosa*, lumber

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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